Book Chapter

Objective Voice Analysis in Partial Deafness: Comparison of Multi-Dimensional Voice Program (MDVP) and VOXplot Results

Karol Myszel[1,2]*

[1]Center of Hearing and Speech, 7 Mokra Street, 05-830 Kajetany, Poland
[2]Faculty of Health Sciences, University of Applied Sciences, 4 Popieluszko Street, 62-510 Konin, Poland

***Corresponding Author: Karol Myszel,** Center of Hearing and Speech, 7 Mokra Street, 05-830 Kajetany, Poland

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Purpose

The purpose of the study was a VOXplot objective analysis of voice in partially deaf individuals and assessment of consistency with results achieved from MDVP analysis as well as with the perceptual assessment.

Material and Methods

Voice samples of 22 post lingual partially deaf individuals (9 females, average age 48,5 years and 13 males, average age 47,7 years) were recorded in sound isolated anechoic conditions after a careful exclusion of preexisting conditions in voice (organic dysphonia, earlier professional voice abuse, respiratory tract diseases, allergies, neurodegenerative and mental diseases). Samples were recorded as continuous speech (cs) and sustained vowel (sv). Control group consisted of 22 healthy individuals (10 females, average age 54 years and 12 males, average age 40 years) with no history of voice and hearing dysfunction. The samples were analyzed with MDVP (multi-dimensional voice profile) by Kay-Pentax, then with VOXplot version 2.0.0 Beta. Statistical analysis was performed with t-Test Paired Two Sample for Means. All individuals were also subjects for perceptual voice assessment with GRBAS by Hirano, performed by two experienced phoniatricians (inter-rater compatibility 92%). Objective measures were then checked for correlations with subjective features by calculation of Pearson correlation coefficient. The study was approved by bioethical committee.

VOXplot software is a tool for objective voice assessment in clinical conditions. It focuses on 13 single voice parameters to ultimately calculate two main, multiparametric indices of hoarseness (AVQI, acoustic voice quality index) and breathiness (ABI, acoustic breathiness index). Validation studies confirmed a strong association of 4 main parameters in detecting and describing hoarseness and breathiness. For hoarseness they include: a) harmonic-to-noise ratio (HNR) and b) pitch perturbation quotient for five periods (PPQ5), and for breathiness: a) smoothed central peak prominence (CPPS) and b) glottal-to-noise excitation ratio (GNE) [1].

HNR (harmonic-to-noise ratio in decibels) often used in acoustic voice analyses is the ratio of the harmonic (periodic) components of the sample to noise components. In healthy voices usually achieves values of 20 dB or higher and generally, the higher values the better voice it represents. The ratio is a strong marker of hoarseness.

PPQ5 (pitch perturbation quotient for five periods) measures the jitter over five periods (less locally) and therefore is regarded to be more precise and robust than jitter local, which refers to the average value of two neighboring periods. The quotient is treated a valuable marker of hoarseness. The lower the value, the less hoarseness in the voice.

CPPS (smoothed central peak prominence) in the studies was described to correlate strongly with auditory voice quality assessments, particularly breathiness. The amplitude of the cepstral peak reflects the harmonic structure of the spectrum. Therefore, the higher the value the better voice it reflects. Based on the studies conducted so far, the values above 14,47 dB for CPPS are usually achieved in healthy voices.

GNE (glottal-to-noise excitation ratio) is used to measure the level of breathiness. Other than HNR itself measuring perturbation noise caused by irregularity of vocal folds vibrations (therefore also reflected by measurements of jitter and shimmer), GNE measures the additive noise caused by turbulences accompanying incomplete vocal folds closure (therefore strongly correlates with breathiness). In contrary to perturbation noise, the additive noise is not reflected in jitter and shimmer. Generally, the higher value of GNE, the better.

Based on the specific parameters measured by VOXplot , two final multi-parametric voice quality indices are calculated for voice samples: AVQI, Acoustic Voice Quality Index which reflects the overall perception of hoarseness and ABI, Acoustic Breathiness Index which reflects the degree of breathiness.

AVQI, Acoustic Voice Quality Index calculation is based upon HNR, Shimmer%, Shimmer dB, Slope, Tilt and CPPS. Higher values reflect the higher degree of hoarseness. In validated versions of VOXplot AVQI usually achieves values from 0 to 10. As research show gender has no influence on AVQI, age has a minimal (almost neglectable) influence and, apart from hoarseness, the index may also show voice anomalies related more strongly to breathiness than roughness.

ABI, Acoustic Breathiness Index calculation is derived from CPPS, Jitter%, GNE, HF Noise, HNR-D, H1H2, Shimmer%, Shimmer dB and PSD. As literature data shows ABI present high sensitivity and utility to measure the degree of breathiness with good diagnostic accuracy. ABI is not sensitive to changes in age, gender and roughness. Therefore, its high sensitivity and exclusivity in measuring breathiness makes it a high value tool in clinical practice [2].

Hearing impairments were widely described in the literature to affect voice quality. Disturbed auditory control of voice leads to dysfunctions of vocal folds (establishing abnormal oscillation patterns), respiratory tract and muscles of larynx which result in abnormalities in pitch, volume and resonance control. The more vocal folds are affected, the bigger part of sound energy is distorted. Abnormalities can be measured objectively and detected in perceptual assessments. VOXplot measures 13 parameters of the voice sample that strongly influence two multiparametric indices: AVQI and ABI. The use of the parameters was accepted by clinical and scientific environments as they are calculated based on a linear regression model combining the most relevant parameters. The benefit of using the two indices is also related to the fact, that the calculation algorithms are derived from Praat freeware and are based on both continuous speech (cs) and sustained vowel (sv). The descriptions of VOXplot parameters were presented in Table 1.

Table 1: Names and descriptions of VOXplot parameters.

Acoustic measure abbreviation	Definition
HNR (dB) (harmonic-to-noise ratio)	Describes the base 10 algorithm of the ratio between the periodic energy and noise energy multiplied by 10 HNR
PPQ5 (%) (jitter of the five-point period perturbation quotient)	Describes the average absolute difference between a period and the average of it and its four closest neighbors divided by the average
CPPS (dB) (smoothed cepstral peak prominence)	Describes the distance between the first harmonic peak and the point with equal quefrency on the regression line through the smoothed cepstrum
GNE (glottal-to-noise excitation ratio)	Describes the glottal-to-noise excitation ratio with a maximum frequency of 4500 Hz
H1H2 (dB) (difference between the first and second harmonics in the spectrum)	Describes the difference between H1 and H2 to localize the first peak and determine F0
HF noise (dB) (high frequency noise)	Describes the relative level of high-frequency noise between the energy from 0 to 6 kHz and energy from 6 to 10 kHz
HNR-D (dB) (harmonic-to-noise ratio from Dejonckere and Lebacq)	Describes the harmonic emergence of the spectral display comprised within the frequency bandwidth between 500 Hz and 1500 Hz
Slope (dB) (general slope of the spectrum)	Describes the difference between the energy within 0-1000 Hz and the energy within 1000-10000 Hz of the long-term average spectrum
Tilt (dB) (tilt of the regression line through the spectrum)	Describes the difference between the energy within 0-1000 Hz and the energy within 1000-10000 Hz of the trendline through the long-term average spectrum
PSD (ms) (period standard deviation)	Describes the variation in the standard deviation of periods in which the length of the sample is important for a valid computation of the standard deviation
Jitter local (%)	Describes the average difference between successive periods divided by the average period
Shimmer (%)	Describes the absolute mean

	difference between the amplitudes of successive periods divided by the average amplitude
Shimmer local (dB)	Describes the base 10 logarithm of the difference between the amplitude of successive periods multiplied by 20

Multi-Dimensional Voice Program (MDVP) measures 33 parameters of voice samples recorded as continuous speech and sustained vowel. Parameters are aggregated in seven groups related to: a) frequency, b) amplitude, c) noise, d) tremor (modulation), e) voice breaks, f) subharmonics, g) irregularities. Results are presented in diagram reflecting the values in a graphical way as well as in a form of spectrogram. Analysis of the diagrams compared to normative values enables detecting which parameters are deviated and to what degree [3,4].

Frequency parameters include Jita, Jitt, RAP, PPQ, sPPQ and vF0. They describe variability of fundamental frequency, relative average perturbation of F0 and its short and long term changes.

Amplitude parameters include Shim, APQ, sAPQ and vAm. They describe amplitude variability and relative amplitude change within a voice sample.

Noise components are characterized by NHR, VTI and SPI parameters. They are used to describe the presence of noise and energy turbulences in a voice sample.

Voice modulation is measured with FTRI and ATRI. These parameters describe the degree of voice tremor.

DVB parameter is used to describe the degree of voice breaks meaning the ratio of total time of voice breaks to the whole time of voice sample.

The presence of subharmonic components is described by DSH. It is represented by a ratio of the number of subharmonics to the whole number of F0 periods within a sample.

To describe voice irregularities DUV parameters is used. It is a number of periods devoid of F0 in a total sample.

The description of main MDVP parameters were presented in Table 2.

Table 2: Names and descriptions of MDVP parameters.

Acoustic measure abbreviation	Definition
Jita (μs) (absolute jitter)	Describes the absolute change of F0 period
Jitt (%) (jitter percent)	Describes the relative variability of F0
RAP (%) (relative average perturbation)	Describes the relative average perturbation (relative change of F0 with a smoothing factor of 3 periods)
PPQ (%) (pitch period perturbation quotient)	Describes the relative change of F0 with a smoothing factor of 5 periods
sPPQ (%) (smoothed pitch period perturbation quotient)	Describes the relative short and long term changes of F0 with a smoothing factor of 1-199 periods
ShdB (dB) (shimmer in dB)	Describes the relative change of amplitude from period to period (in decibels)
Shim% (shimmer percent)	Describes the relative change of amplitude from period to period (in percent)
APQ (%) (amplitude perturbation quotient)	Describes short term changes of amplitude from cycle to cycle with a smoothing factor of 11 periods
sAPQ (%) (smoothed amplitude perturbation quotient)	Describes the relative changes of amplitude with a smoothing factor of 1-199 periods
vAm (%) (peak amplitude variation)	Describes the relative standard deviation of amplitude from cycle to cycle
NHR (noise-to-harmonic ratio)	Describes the average ratio of non-harmonic energy of the spectrum in 1500-4500 Hz to its harmonic energy in 70-4500 Hz
VTI (voice turbulence index)	Describes the average ratio of non-harmonic energy of the spectrum in 2800-5800 Hz to its harmonic energy in 70-4500 Hz
SPI (soft phonation index)	Describes the average ratio of harmonic energy of the spectrum in 70-1600 Hz to its harmonic energy in 1600-4500 Hz

FTRI (%) (F0 tremor intensity index)	Describes the ratio of frequency of the most intensive modulating component (tremor) to F0 of the sample
ATRI (%) (amplitude tremor intensity index)	Describes the ratio of average amplitude of modulating components in 30-400 Hz to average maximum amplitude
DVB (%) (degree of voice breaks)	Describes the ratio of the total time of voice breaks to the total length of the voice sample
DSH (%) (degree of subharmonics)	Describes the ratio of the number of subharmonic tones to the total number of F0 periods
DUV (%) (degree of voiceless)	Describes the relative number of non-harmonics (without F0) in a total voice sample

Results

The results achieved in the study showed that major differences can be observed in 13 VOXplot parameters measured in voice samples of PD adults compared to those in control group. Decrease was reported in Slope, Tilt, HNR-D, HNR, CPPS and HF Noise and all of the reported changes, excluding HF Noise, presented a statistical importance.

Other parameters: Shimmer %, Shimmer dB, Jitter local, Jitter ppq5, GNE and H1H2 showed an increase and all of the reported changes presented a statistical importance.

Both multiparametric indices noted a statistical increase: AVQI achieved value 4,96 (SD=0,8) vs 0,35 in control group and ABI achieved value 6,24 (SD=0,89) vs 1,23 in control group. The reported changes reflect the voice of partial deafness individuals to be hoarse and breathy. The average values of parameters in partial deafness patients and in control group are presented in Table 3.

Table 3: Average values of VOXplot parameters in partial deafness adults vs control group.

	Average in PD patients	Standard deviation	Average in control group	Standard deviation	p-value
Slope (dB)	-14,55	4,50	-12,72	3,28	p<0,05
Tilt (dB)	-10,52	1,30	-7,71	1,36	p<0,05
HNR-D (dB)	18,48	1,82	31,79	3,6	p<0,05
HNR (dB)	13,85	4,03	23,91	2,27	p<0,05
Shimmer (%)	7,95	3,21	1,86	1,25	p<0,05
Shimmer (dB)	0,80	0,25	0,27	0,37	p<0,05
CPPS (dB)	6,26	1,49	19,21	1,47	P<0,05
Jitter local (%)	1,40	0,68	0,21	0,11	p<0,05
Jitter ppq5 (%)	0,65	0,33	0,14	0,07	p<0,05
GNE	0,95	0,03	0,89	0,06	p<0,05
HF Noise	1,26	0,23	1,38	0,34	p>0,05
H1H2	3,15	2,36	1,53	2,46	P<0,05
PSD	0,84	0,67	0,38	0,57	p>0,05
AVQI	4,96	0,80	0,35	0,67	p<0,05
ABI	6,24	0,89	1,23	0,48	p<0,05

In the next step a comparison was conducted to check whether the results achieved in VOXplot analysis are consistent with MDVP and perceptual analysis. As literature shows among all MDVP parameters, some of them: Jitt%, vF0, Shim dB, APQ, NHR, SPI and VTI are strongly associated with a perception of hoarseness, whilst Shim dB, APQ, NHR, SPI and NSH are associated with perception of breathy voice and present statistical correlations with breathy voice.

To check whether consistency exists between observations done with VOXplot and MDVP, groups of MDVP parameters correlating with hoarseness and breathiness were compared with VOXplot parameters most influencing the index of hoarseness (AVQI) and breathiness (ABI) respectively, and finally with the final values of the two multiparametric indices themselves.

Interestingly, MDVP analysis showed that all seven parameters correlating with hoarseness were elevated, and five of them (Jitt%, vF0, Shim dB, APQ, NHR) presented a statistical increase. VOXplot parameters associated with hoarseness in the same group of partial deafness patients were also changed, and all of them presented a statistically significant change indicating hoarseness: Shim %, Shim dB increased whilst HNR, Slope, and CPPS decreased. Consistently with VOXplot methodology, the directions of above mentioned changes reflect a hoarse voice in PD patients. As result, AVQI was elevated too with a statistical significance. Therefore, VOXplot results appeared to be consistent with MDVP parameters related to hoarseness. Both tools of objective analysis detected hoarseness in voice of partially deaf individuals with statistical significance.

When it comes to MDVP parameters correlating with breathiness, all of them (Shim dB, APQ, NHR, SPI and NSH) were increased in partial deafness patients reflecting a breathy voice. Only one increased parameter SPI, did not present a statistical importance. VOXplot parameters associated with breathy voice were also changed , and all but PSD, were increased with statistical significance. Consistently with VOXplot methodology, the directions of above mentioned changes reflect a breathy voice in PD patients. As result, ABI was elevated with a statistical significance. Therefore, VOXplot results appeared to be consistent with MDVP parameters related to breathiness. Both tools of objective analysis detected a breathy voice of partially deaf individuals.

Table 4 below presents MDVP parameters correlating with hoarseness and breathiness compared with respective VOXplot results.

Table 4: MDVP parameters correlating with hoarseness and breathiness compared with respective VOXplot results.

	MDVP				VOXplot			
		Partial deafness	Control	P value		Partial deafness	Control	P value
HOARSENESS	Jitt %	1,84	0,40	< 0,05	Shim%	7,95	1,86	< 0,05
	vF0	8,4	0,74	< 0,05	Shim dB	0,8	0,27	< 0,05
	Shim dB	0,73	0,27	< 0,05	HNR	13,85	23,91	< 0,05
	APQ	6,41	1,8	< 0,05	Slope	-14,55	-12,72	< 0,05
	NHR	0,2	0,12	< 0,05	Tilt	-10,52	-7,77	< 0,05
	SPI	10,31	8,72	> 0,05	CPPS	6,26	19,21	< 0,05
	VTI	0,06	0,04	> 0,05	**AVQI**	**4,96**	**0,35**	**< 0,05**
BREATHINESS	Shim dB	0,73	0,27	< 0,05	Jitter%	1,4	0,21	< 0,05
	APQ	6,41	1,8	< 0,05	Shim dB	0,8	0,27	< 0,05
	NHR	0,2	0,12	< 0,05	GNE	0,95	0,89	< 0,05
	SPI	10,31	8,72	> 0,05	H1H2	3,15	1,53	< 0,05
	NSH	0,55	0	< 0,05	PSD	0,84	0,38	> 0,05
					ABI	**6,24**	**1,23**	**< 0,05**

Perceptual assessment of voice in a study group was performed with Hirano GRBAS scale showed hoarseness in 21 of 22 individuals and breathiness in 19 of 22 individuals. Hoarseness G1 was present in 19 patients, G2 in 2 patients. G0 was rated only in 1 individual and G3 in none of them. Breathiness of B0 was rated in 3, B1 in 17 and B2 in 2 individuals. None of patients was rated B3. Subjectively, voice of adults with partial deafness was therefore assessed as slightly or moderately hoarse and breathy.

Correlations of feature G were noted with MDVP parameters (vF0, Shim dB, APQ, SPI) and VOXplot parameters (Shim%, Shim dB, HNR, Slope, Tilt, CPPS, GNE, H1H2). Correlations of feature B were noted with MDVP parameters (vF0, Shim dB, APQ, NHR, SPI, NSH) and VOXplot parameters (Shim%, Shim dB, Slope, Tilt, GNE, H1H2).

There is a high consistency of results between MDVP and VOXplot. All voice evaluation methods used in the study of adults with partial deafness revealed their hoarse and breathy voice.

Table 5 below presents the values of correlation coefficient (R Pearson) between respective objective parameters and G and B in perceptual assessment.

There is a high consistency of results between MDVP and VOXplot. All voice evaluation methods used in the study of adults with partial deafness revealed their hoarse and breathy voice.

Table 5: values of correlation coefficient (R Pearson) between respective objective parameters and G and B in perceptual assessment.

	Parameter	G	B
MDVP	Jitt %	-	-
	vF0	0,68	0,38
	Shim dB	0,74	0,46
	APQ	0,25	0,20
	NHR	-	0,78
	SPI	0,24	0,28
	VTI	-	-
	NSH	-	0,88
VOXplot	Shim%	0,49	0,46
	Shim dB	0,34	0,23
	HNR	0,46	-
	Slope	0,30	0,32
	Tilt	0,47	0,44
	CPPS	0,47	-
	Jitter%	-	-
	GNE	0,50	0,35
	H1H2	0,67	0,46
	PSD	-	-

Discussion

Objective analysis of voice is a valuable tool to track voice changes and describe them in mathematical, comparable matter. In clinical practice many different tools of objective assessment are used. MDVP and Praat systems seem to be the most commonly used, however VOXplot based on Praat has been getting more attention recently for its updated utility, confirmed correlations with coefficients for hoarseness and breathiness, as well as for enabling measurements using multiparametric models [5].

Various reasons of voice disorders, resulting in dysfunctions of vocal tract or respiratory system, lead to abnormal mass, mobility and oscillation patterns of vocal folds. Disturbed vocal function and abnormal air passage can be detected by objective measurements [6]. For this reason, objective voice analysis, is commonly used in the diagnostics of different types of voice abnormalities, both organic and functional. For many years, objective voice measures have been recommended for clinical use as a precious part of overall voice diagnostics [6-12].

Functional voice disorders associated with hearing impairment were subject of analysis for many researchers [13-25]. The research performed first time ever in the Institute of Physiology and Pathology of Hearing in Warsaw in individuals with partial deafness (normal hearing thresholds up to 1 kHz and deep hypoacusis at high frequencies) showed that this group of patients presents voice abnormalities as a result of an inappropriate auditory control of voice production. Voice characteristics discrepancies versus normal hearing people are detected in objective measurements using MDVP tool, particularly those related to frequency, amplitude, noise and tremor. Perceptually, partial deafness individuals develop voice with small degree of hoarseness, slightly harsh, breathy, slightly asthenic and tense. Analyses reveal correlations between objective and subjective voice evaluation [26].

Whilst MDVP measures specific parameters described individually, VOXplot measures several parameters, which come into the final measurement of two multiparametric indices: AVQI (acoustic voice quality index) that generally describes the level of hoarseness (reflecting disturbed vocal fold ocscillation), and ABI (acoustic breathiness index) that describes voice dysfunction presented with breathiness (reflecting incomplete glottal closure) [27-30].

The study was aimed to compare the results of voice analysis in patient with partial deafness conducted with the use MDVP. Acoustic parameters measured by MDVP relate to frequency, amplitude, noise, tremor, voice breaks, presence of subharmonics and voice irregularities. In many studies those parameters present correlations with subjective voice assessment. Research and observations were conducted to identify which of the objective measures correlate the most with perception of hoarseness and breathiness. Literature review shows that some parameters of frequency (Jita, Jitt, RAP, PPQ, vF0), amplitude (shimmer, APQ), and noise (HNR) are mostly related to hoarseness whilst tremor parameter (FTRI) and voice irregularities (DUV) are strongly correlated with harsh voice. Breathy voice in perceptual analysis is strongly associated with amplitude (shimmer, APQ), noise (NHR, SPI) and subharmonics (NSH) [31-34].

To see whether objective measurements of voice acoustics performed by VOXplot correspond with those done by MDVP, parameters related to hoarseness and breathiness were grouped and checked for the levels and directions of changes presented in partially deaf people. Comparison shows that both MDVP and VOXplot give similar results as it comes to voice acoustics analysis of individuals with partial deafness.

Conclusions

Both MDVP and VOXplot objective assessment of voice in partially deaf patients showed abnormalities compared to control groups. There is a high level of consistency in results achieved.

MDVP measurements revealed statistically significant changes mainly in frequency, amplitude, noise and tremor parameters. Most of those parameters correlating with perception of hoarseness and breathiness achieved statistical changes and correlated with GRBAS findings. VOXplot analysis showed that increases of acoustic voice quality index (AVQI) and acoustic breathiness index (ABI) were statistically significant. Correlations were also found with GRBAS assessment results.

Both systems appeared to be effective in detecting voice abnormalities in patients with partial deafness. Findings were consistent when it comes to correlates of hoarseness and breathiness. Besides, VOXplot analysis became a doublecheck reconfirming the existence of voice dysfunctions in partial deafness individuals, which makes an important addition to our knowledge, as very few studies on this topic were done so far.

Limitations of the Study

The research had some limitations related to number of subjects in the study. Better understanding of the topic can be achieved by enlarging the study group and validating the VOXplot tool on a bigger group of individuals in Polish, which will be continued.

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